
Supernova statistics

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Summary. The statistics of SN discoveries is used to reveal selection biases of past and current SN searches and to gain insight on the progenitor scenarios for the different SN types. We also report estimates of the SN rate per unit mass in galaxies of different types and on the first attempts to study the evolution of the supernova rate with redshift.

1 Counting Supernovae

Event statistics is an invaluable tool to link the different supernova types to their parent stellar populations and in turn to assess the consistency of the possible progenitor scenarios. Since the early days of SN research, the simple observation that type Ia SNe are found in all type of galaxies, including ellipticals where star formation ceased long time ago, is used to deduce that their progenitors must be low mass, long lived stars. Today the standard scenario for type Ia calls for an accreting white dwarf in a close binary system which explodes when it reaches the Chandrasekhar mass. However, the real nature of the progenitor system has not yet been identified and the different candidates, eg. double degenerate or single degenerate, have still to pass the basic test of the occurrence statistics [1].

Type II and Ib/c SNe are believed to be the outcomes of the core collapse of stars with mass larger than 8-9 M_{\odot} . Different sub-types have been related to progenitors with different initial masses and/or metallicities [2]. Since only for a few events it has been possible to collect direct informations on the progenitors [3], one of the basic tool of investigation remains the event statistics in systems with different stellar populations.

It is fair to say that the new interest for SNe in the last few years has been driven not just by the wish to understand their physical properties but mainly by their role as cosmological probes, in particular the use of type Ia to measure the geometry of the Universe. In addition, we believe that measurements of the SN rates as a function of redshift is an attractive tool to recover the history of the star formation rate with the cosmic age [4, 5].

2 SN Searches

At a rate of a few hundreds discovery per year, the number of known SNe doubled in the last 5 years for a total count of over 2500 events⁴. Yet, the discovery rate of bright events, those < 15 mag at discovery, remains more or less constant, at about 10 SN/year. This may appear to confirm the common assumption that in modern time, say after 1970, all the SNe which exploded in the local Universe were discovered [7]. However, although most of the faint SNe discovered in the last decade are distant events, there is also a significant contribution for nearby SNe. This can be seen in Fig. 1 where we compare the apparent magnitude distribution of the SNe discovered in the local Universe ($v_{hel} < 1200 \text{ km s}^{-1}$) in two different periods, the last decade and the twenty years before. It turns out that the discovery rate in nearby galaxies is today almost a factor 2 larger than in the past and that the average apparent magnitude at discovery is about 1 mag fainter.

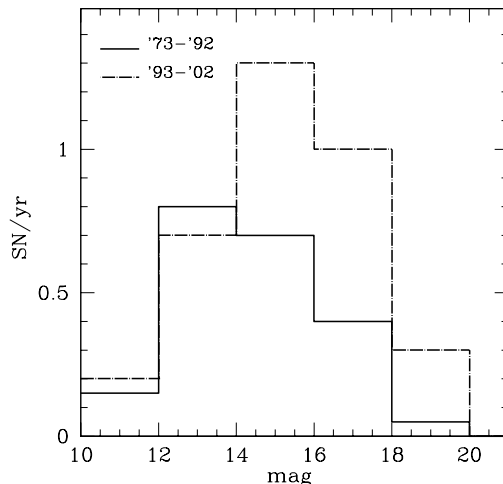


Fig. 1. Distribution of the apparent magnitude for the nearby SNe (recession velocity $v_{hel} < 1200 \text{ km s}^{-1}$) discovered in two periods: the last decade (1993–2002) and the preceding twenty years (1973–1992)

It is important to stress that among the faint, nearby events there are not only those SNe that, due to seasonal observational limitations, were discovered long after maximum, but also highly extinguished events (eg. SN 2002cv [8]) and intrinsically faint SNe (eg. SN 1997D [9]).

The presence of such bias explains why the absolute value of the SN rate cannot be derived from the general list of SNe but instead through a detailed analysis of the

⁴ See <http://www.pd.astro.it/supern/snean.txt> for an up-to-date version of *The Asiago SN Catalogue*. [6]

data of an individual SN search, for which actual limits and biases can be carefully accounted for.

The main problem, when considering the data of an individual SN search, is that the statistics is not very large, especially when considering less frequent SN types. Therefore the analysis of the relative SN rates from the general list can still be of interest. In Fig. 2 we report, in a separate panel for each of the three main SN type (Ia, II and Ib/c), the SN counts as a function of galaxy type. It results that the discovery rate of type Ia SN appears more or less independent on galaxy type, while the core collapse SN rate rapidly increases from early to late type spirals. The latter gives a very close match of the current estimates of the star formation rate in galaxies of different type (cf. Fig.3 in [11]) and directly reflects the fact that SN II derive from massive, short lived progenitors. An intriguing feature which is seen in Fig. 2 is the spike for type Ib/c SNe in Sc galaxies which, because of a similar peak in the star formation rate, suggests that, in the average, their progenitors are more massive than those of normal type II SNe. We should note that this effect seems to be washed-out when using, instead of the RC3 galaxy classification system as in the Asiago SN catalogue, the DDO system [12].

Because of the peak of the SFR, the ratio of the events in Sc galaxies compared to the total counts for a given SN type can be used to rank the SN types according to their progenitor masses. This ratio results $12 \pm 1\%$ for type Ia, $19 \pm 2\%$ for type II and $34 \pm 6\%$ for type Ib/c which gives the same indication of Fig. 2 in a different form and can be used as reference to derive some hints for less frequent SN sub-types. For instance, we found that the same ratio for type IIn is $24 \pm 6\%$ which suggests that these SNe have in average the same progenitor mass, or maybe even somewhat higher, than normal type II. This has become interesting after the discovery of SN 2002ic [13], a SN Ia showing evidence of interaction with a dense H envelope and, at late time, developing a spectrum very similar to that of some type IIn like SN 1997cy. That this is the most common channel for type IIn is not consistent with the fact that their progenitors, in the average, seems to be massive (cf. [12]).

Another example is that of faint type II SNe [9]. These low energy explosions delivering one order of magnitude less Ni than normal type II have been related to the formation of a black hole rather than to a neutron star. This is attributed to their progenitors being more massive than those of normal SNII [14, 15] and it is consistent with the fact that out of 10 events, 5 occurred in Sc galaxies.

3 SN Rates

As we mentioned before, the absolute value of the SN rates requires that the detection efficiency and selection biases of individual SN searches are accurately estimated. At the same time, it is important to maintain a sufficient statistics for SN events which, especially in the past, was not achievable using one search alone. An obvious solution is to pool the data from a few systematic SN searches as in [16]. Somewhat surprisingly, these most significant results still relay on photographic and/or visual SN searches whereas the legacy of the modern systematic CCD SN searches have still to be exploited.

One of the main uncertainties on the current estimate of the SN rates is the bias against SN detection in spiral galaxies which are not seen face-on. Likely, this is due to the fact that the larger optical depth through the dust, and hence the

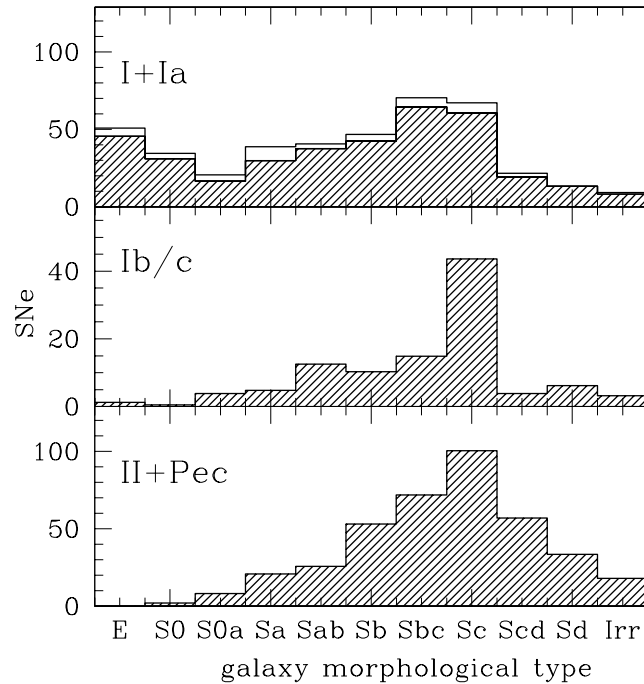


Fig. 2. SN counts for galaxies of different morphological type for the three main SN types, normalised to the fraction of galaxy of the given type as derived from the RC3 galaxy catalog [10]. Only SNe at redshift $z < 0.05$ have been included. In the upper panel the shaded area are type Ia SNe only

higher extinction, makes the average SN in inclined spirals fainter than in face-on ones. It is often claimed that the effect was only important for photographic surveys whereas modern CCD searches, due to the better spectral sensitivity in the red, are less affected. Although this is certainly true, the inclination effect does remain important. This is shown in Fig.3, where the SN discovery counts in spiral galaxies of different inclination are compared for different grouping of galaxy and SN types. Only SNe discovered in the last 5 years, hence mainly in systematic CCD searches, have been included. It turns out that taking as reference the discovery rate in face-on spirals ($i < 30^\circ$), even in the present day SN searches we are missing half of the type Ia and 2/3 of the core collapse SNe occurring in edge-on spirals ($i > 60^\circ$). We stress that although it may occur that in some SN searches face-on galaxies are monitored more frequently, it is not expected that this depends on galaxy or SN type.

After Tammann [17], the rate of SNe is usually normalized to the galaxy blue luminosity ($\text{SNU} = \text{SN } 10^{-10} L_\odot^B 10^{-2} \text{yr}$). This is convenient because *a*) the luminosity can easily be measured for large galaxy samples and *b*) the SN rate has been found to be proportional to the galaxy luminosity. However, while interpreting the results,

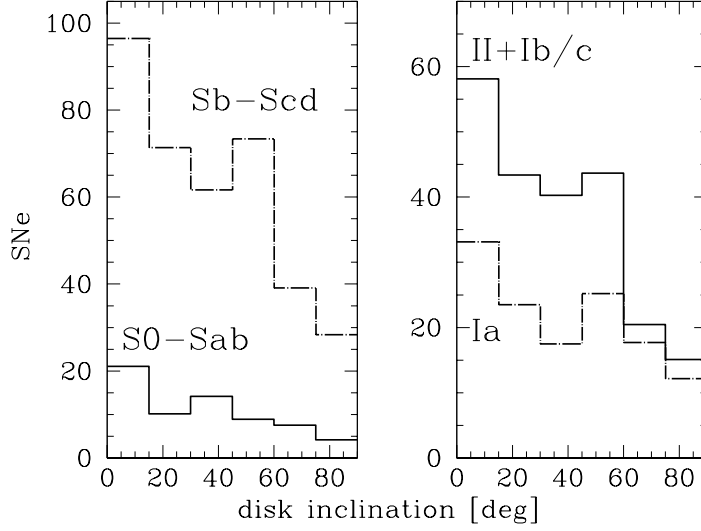


Fig. 3. SN counts in spiral galaxies of different inclinations (0 deg is for face-on galaxies) normalized to the fraction of galaxies in each bin of inclination as given in the RC3. In the left panel we show separately early and late type spirals, whereas in the right panel we distinguish core collapse (II+Ib/c) from thermonuclear (Ia) Supernovae. Only the SNe discovered after 1998 have been included.

it has to be taken into account that there are different contributors to a galaxy blue luminosity depending on its stellar population mixture. Indeed it is well known that the mass to light ratio (M/L) changes by one order of magnitude along the Hubble galaxy sequence. We can convert SN rate per unit luminosity to SN rate per unit mass assuming an average M/L for each galaxy type [18]. The results are reported in Tab. 1.

It is known that for SN Ia the rate per unit luminosity remains almost constant moving from ellipticals to spirals. On the other side as it can be seen from Tab. 1, because M/L is lower, the rate of SNIa per unit mass in late spirals is almost 3 times higher than in ellipticals. This implies that a fraction of SN Ia in spirals must be related to a relatively young stellar population.

Because of the short time scale of evolution of massive stars, the core collapse (II+Ib/c) SN rate can be translated in the present time star formation rate if we know the initial mass function and the mass range of core collapse progenitors. Assuming a Salpeter mass function (with index 1.35) and choosing 8 and 40 M_{\odot} for the lower and upper limits of core collapse progenitor masses, from the measured core-collapse SN rates we derive that in a $10^{11} M_{\odot}$ Sbc-Sd galaxy of the local Universe the star formation rate is $1.8 M_{\odot} \text{ yr}^{-1}$, in S0a-Sb is $0.7 M_{\odot} \text{ yr}^{-1}$, whereas for E-S0 we derive an upper limit of $0.01 M_{\odot} \text{ yr}^{-1}$. These numbers strongly depend on the

lower mass limit for core collapse progenitors which is not well known. For instance if we take for the latter $10 M_{\odot}$ the estimate of the star formation rates increases by $\sim 40\%$.

Table 1. SN rate per unit mass [$10^{-11} M_{\odot} 10^{-2} \text{yr} \times (H/75)^2$].

galaxy type	SN rate			
	Ia	Ib/c	II	All
E-S0	0.16 ± 0.03	< 0.01		0.16 ± 0.03
S0a-Sb	0.29 ± 0.07	0.16 ± 0.07	0.69 ± 0.17	1.14 ± 0.20
Sbc-Sd	0.46 ± 0.10	0.30 ± 0.11	1.89 ± 0.34	2.65 ± 0.37
All	0.27 ± 0.03	0.11 ± 0.03	0.53 ± 0.07	0.91 ± 0.08

4 Evolution of the SN rate with redshift.

Estimates of the supernova rate, in particular that of core collapse SNe at different redshifts can be used to recover the history of star formation with cosmic age. Conversely, if the latter is known, it is possible to constrain the SN progenitor scenario which is especially important for type Ia which has not yet been firmly established. Despite of these prospectives, very few observational estimates have been published to date and all rely on the major efforts devoted to the search of type Ia to be used as cosmological distance indicators. This means that *a)* only type Ia rate have been measured and *b)* the search strategy introduces severe biases. In particular, to allow for accurate photometry, the candidates found in the galaxy inner regions and/or in bright galaxies are usually rejected.

A further concern is that little is known about the properties of the galaxy sample. Among other things, this makes impossible to verify the presence of a spiral inclination effect such as in the local Universe. We stress that although high redshift SN searches are usually performed in the red (R or I band), the host galaxy extinction occurs in the SN rest frame wavelength (ie. B or V for $z \sim 0.5$). Therefore if in galaxies at $z \sim 0.5$ the dust content and properties are the same as in the local Universe, we expect similar biases.

The few available estimates seem to indicate an evolution of the type Ia SN rate with redshift. At $z = 0.55$ the measured value is $0.33_{-0.05}^{+0.06} (H/75)^2 \text{ SNU}$ [19] to be compared with the local estimate (not corrected for host galaxy inclination) of $0.14 \pm 0.04 (H/75)^2$ [16]. Taken as a face value, this indicates a very rapid increase of the SN Ia rate. However, due to the large uncertainty, this is still consistent with the current scenario of galaxy and SN Ia progenitor system evolution [20].

In the last few years we started a long term project which is especially designed to measure SN rates and to overcome some of the previous limitations. In particular we try to:

1. reduce as much as possible the candidate selection biases. Indeed we do count candidates in the galaxy nuclear region (but we try to reduce the contamination from variable AGN using the long term variability history of the source).

2. count both type Ia and core collapse SNe. Core collapse SN rate can be used to constraints the star formation rate at the given redshift. Besides, relative SN rates have smaller systematic errors than absolute values.
3. use photometric redshift to characterize the galaxy sample

The first results of this program are now becoming available [4] and indicate that the rate of core collapse SNe grows at a faster pace than SN Ia. In particular we found evidence that the star formation rate at $z = 0.30$ is a factor 3 higher than in the local Universe. Although this is a preliminary result it confirms similar finding based on the measurements of the $H\alpha$ emission from galaxies at the same redshift [21]. The coming in operation of new wide field telescopes (eg. VST+OmegaCAM [23, 22] and LBT+LBC [24]) will give the chance to strongly improve the statistics and to probe different redshifts.

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